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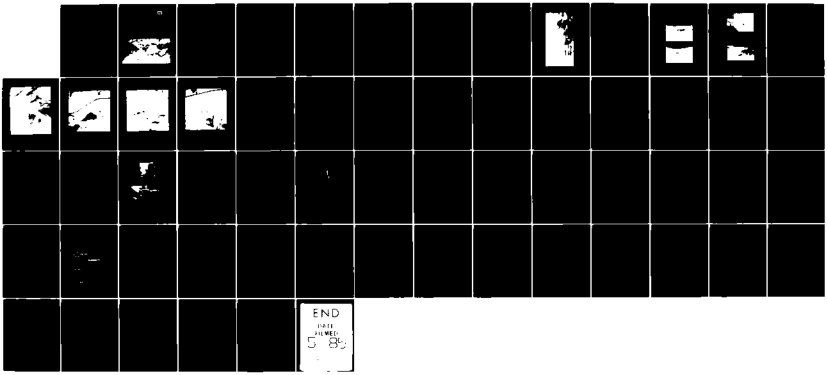

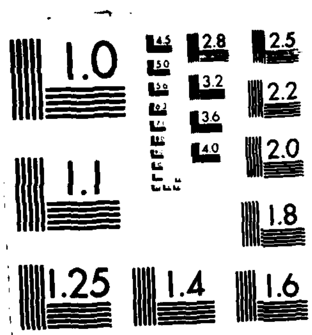
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July 1984

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Tanana River monitoring and research program

Relationships among bank recession, vegetation, soils, sediments and permafrost on the Tanana River near Fairbanks, Alaska

Lawrence W. Gatto

Prepared for
U.S. ARMY ENGINEER DISTRICT, ALASKA
as part of the
TANANA RIVER MONITORING AND RESEARCH PROGRAM

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The objective of this analysis ~~was~~ to determine if available data are useful in identifying the characteristics that contribute to erodibility of the banks along two reaches of the Tanana River. Existing data on bank vegetation, soils, sediments, and permafrost were ~~used~~. Because these data were general and not coll..cted for the purpose of site-specific analysis, ~~my~~ analytical approach was simple and did not include any statistical tests. The data were visually compared to the locations and estimated amounts of historical recession to evaluate if any relationships were obvious. The results of this analysis showed no

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useful relationships. Vegetation was similar in eroded and uneroded areas and its distribution did not show any obvious relationship to the locations of bank recession. Surface sediments and soils in the eroded areas had little, if any, effect on bank erodibility because the river erodes the bank over its entire depth, which is well below this surface zone. The subsurface sediment from eroded and uneroded wells and along transects with high and low measured recession was similar. Permafrost occurrences are about equal in eroded and uneroded sites, although it appears that recession can be higher where permafrost is common than where it is absent. In most cases the existing data are either too general or not properly located to be useful in anticipating future locations of bank erosion. In order to predict future erosion, a field project should be initiated to evaluate the influences of bank characteristics and hydraulic forces on bank erosion rates.

PREFACE

This report was prepared by Lawrence W. Gatto, Geologist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. It was originally Appendix B in the CRREL contract report "Overview of Tanana River Monitoring and Research Studies near Fairbanks, Alaska." The work was funded by the U.S. Army Engineer District, Alaska, under Intra-Army Order E-86-82-0005, Tanana River Monitoring and Research Program.

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RELATIONSHIPS AMONG BANK RECESSION, VEGETATION, SOILS, SEDIMENTS AND PERMAFROST ON THE TANANA RIVER NEAR FAIRBANKS, ALASKA

Lawrence W. Gatto

INTRODUCTION

The Corps of Engineers, Alaska District, is responsible for the planning and construction of groins along the flood control levee between Fairbanks and the Tanana River (Fig. 1). The groins will be placed to divert the river southward from the north bank so as to stop bank erosion and bankline recession. The Corps plans to build additional groins as required to protect the levee from being undermined by bank erosion and to maintain 500 ft of land between the levee and the river. Any information on where future north bank erosion will likely occur would be useful to the Corps in planning the requirements for groin construction.

Objectives

This analysis was done to determine if the selected banks have characteristics that make them erodible and if these characteristics are identifiable from available data on bank vegetation, soils, sediments and permafrost. If the existing data could be related to historical bank recession, then these data could be used to anticipate where future bank erosion and recession would occur.

The available data, compiled from maps and well logs, were, however, not intended for a site-specific, comparative analysis such as this. Because these general data were not collected at locations proper for this type of study, detailed statistical analyses were neither warranted nor applicable. Consequently the comparative analyses were intentionally simple.

Background

The roles of vegetation, soils, sediments and permafrost in influencing river bank erodibility are not firmly established, although it is agreed that they influence the rates of bank erosion and recession. In Alaska, the effect of permafrost on erodibility is perhaps the factor about which there is most debate. This disagreement is apparent in the papers reviewed by Scott (1979) and Lawson (1983).

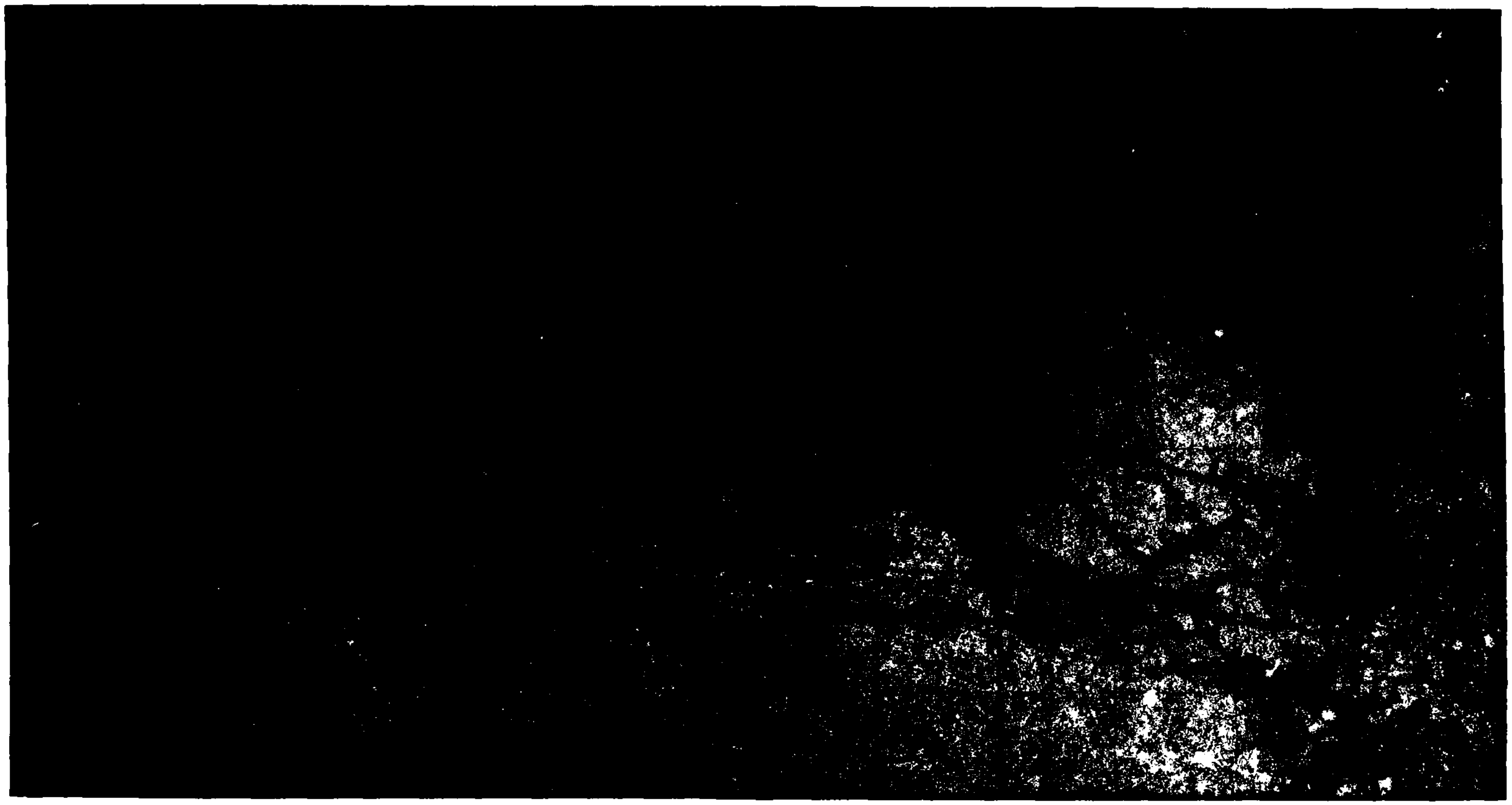


Figure 1. Location map (from USGS 1:63360 Fairbanks D-2 quadrangle).

In general terms, the Fairbanks area is in the discontinuous permafrost zone (Ferrians 1965, Ferrians et al. 1969), as it is underlain by areas of moderately thick to thin permafrost in fine-grained deposits and by isolated masses of permafrost in coarse-grained deposits. Some investigators report that ice-rich permafrost increases bank recession beyond what would occur if ground ice were absent, because thermal erosion of the ground ice adds to the volumes of bank material eroded by river water abrasion alone (Lewellen 1972, Shamanova 1971). The higher the ice content in a bank, the faster the bank erosion (Are 1977, Shamanova 1971, Miles 1977).

In addition, thermal erosion (and consequently bank recession) may be more rapid when water is in contact with the frozen bank zone (Jahn 1975, Are 1977) and when either the temperature of the ice-rich permafrost is near 0°C or the water temperature is warm (Are 1977, Cooper and Hollingshead 1973, Jahn 1975).

Other investigators conclude that frozen sediments are harder to erode by fluvial action than unfrozen sediments (Outhet 1974) and permafrost tends to stabilize material that, if unfrozen, would be inherently unstable (Cooper and Hollingshead 1973). Consequently, permafrost may slow bank erosion and recession. Scott (1978) concluded that the frozen material has no direct effect on the rate of erosion if the bank erosion rate is lower than the thaw rate of bank permafrost; conversely, the frozen bank will retard erosion if the erosion rate is greater.

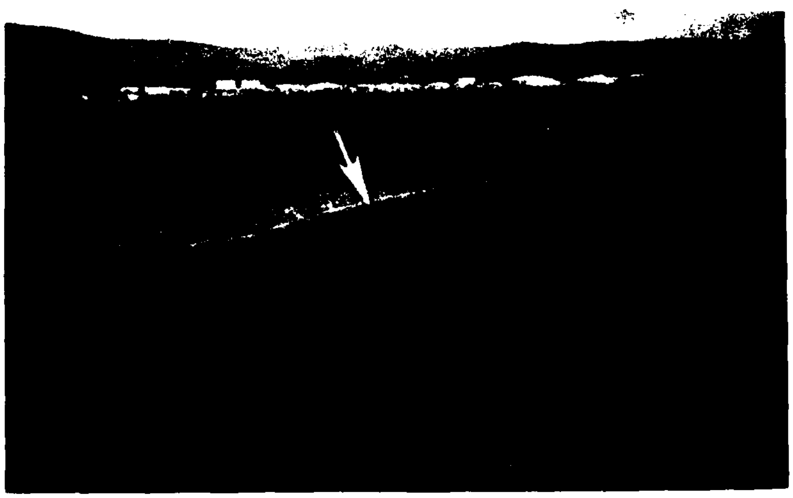
The question of the effects of permafrost on the erodibility of a bank is complicated by many factors: bank sediment texture and properties, ice structure of the permafrost, vegetation, river stage, bank aspect, current velocity, water temperature and angle of attack (severity of erosive attack) (Are 1977, Cooper and Hollingshead 1973, Jahn 1975, Lawson 1983, Miles 1977, Ritchie and Walker 1974, Scott 1978, and Smith 1976).

My purpose is not to try to resolve the disagreements regarding the effect that permafrost has on bank erosion. This would require a detailed, site-specific field study of selected river bank reaches. I mention this ongoing debate simply to point out a few of the factors that influence erosion and to emphasize the potential effects of permafrost on bank erosion along the Tanana River.

APPROACH

The Corps of Engineers, Alaska District, and CRREL personnel selected reaches 1 (Figs. 1 and 2) and 2 (Fig. 3) for analysis. It was understood that reaches 3 and 4 (Fig. 1) might be analyzed later if the results of this initial analysis showed that existing data could be useful for anticipating where future erosion may occur.

a. Upstream end of revetment.



b. Downstream end of revetment.

Figure 2. Upstream portion of reach 1 with riprap revetment (white arrow), 2 October 1980.

c. Bank erosion just downstream of revetment. Not the sandy-silt bank sediment (field book for scale).

Figure 2 (cont'd).

Figure 3. Upstream portion of reach 2, 9 May 1980; USGS gauging station (A) and the approximate location of well 43(B).

Data sources

The vegetation and soils information were obtained from available maps that show unit distributions throughout the Fairbanks area. As with all general maps, characteristics at a particular site may vary from the regional descriptions. Although these maps may be of debatable utility, no site-specific vegetation or soils data were available.

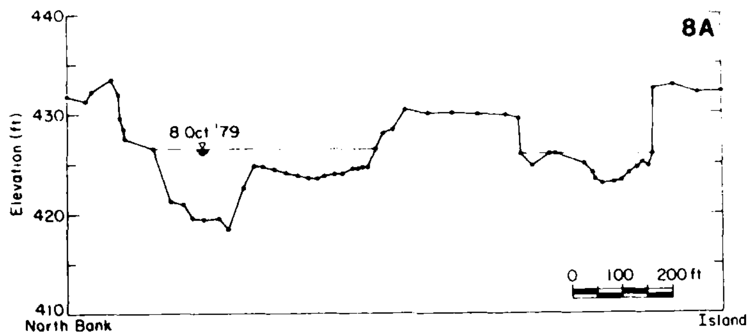
A broader range of data was available on sediments and permafrost. General information was taken from maps, and site-specific data were obtained from the logs of wells drilled by the Corps of Engineers. The well log data were collected for pre-construction analysis of the subsurface conditions along the planned route of the flood control levee. Consequently, the wells were drilled along or near this route, which runs approximately parallel to the bank, but not near the riverbank at most locations (Fig. 1).

The Corps classified the sediments from the wells according to the Unified Soil Classification System (Tables A1-A3). For comparison, Table A4 shows sediment sizes expressed in different scales. Descriptions of specific engineering characteristics of the sediments and nature of the permafrost are not included in the well logs, although information on the following are usually provided: color, presence or absence of organics and ice crystals, depth of seasonal frost and water table, ground water flow rate, percentage of silt, sand and gravel at sampled depths, layering within a given sediment type, penetration rate during drilling, and whether the sediment was frozen or wet.

Analytical methods

Initially, I transferred the Corps' well locations from maps onto base photographs (Fig. 4) and superimposed historical bankline positions onto the vegetation, soils and general sediment maps using a zoom transfer scope. The process of transferring and superimposing with a zoom transfer scope is, however, somewhat inaccurate.

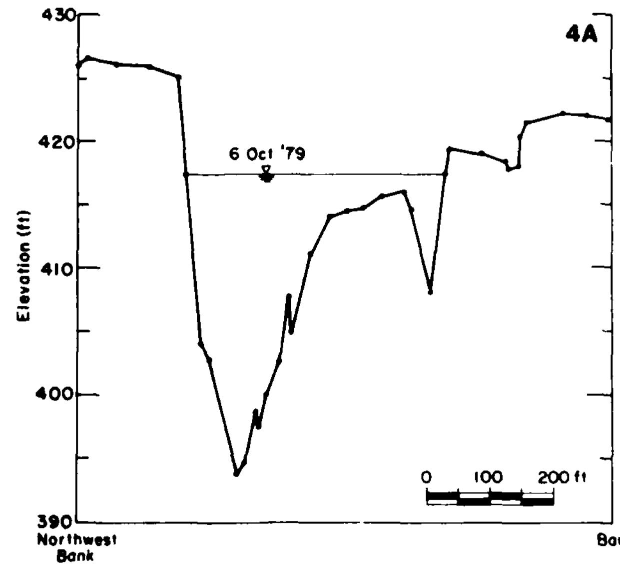
I then plotted the sediment logs and categorized them in 5-ft depth intervals from the bank surface to the approximate depths that could be eroded by the river. These depths were obtained from available river cross sections. I had to assume for this analysis that the sediments and permafrost in a local area were similar to those in the closest well. Clearly this assumption may be invalid, but it was necessary in order to use the well log



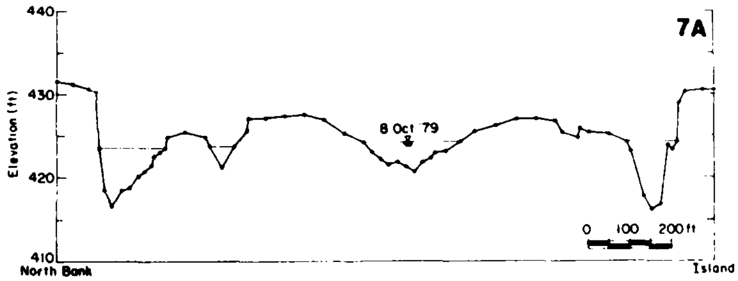
c. Cross section 8A.

d. Cross section X9.

Figure 8 (cont'd). Cross sections 4A, 7A, 8A and X9.



a. West part of cross-section 4A (locations on Fig. 4).



b. Cross section 7A.

Figure 8. Cross sections 4A, 7A, 8A and X9.

(unit 2) than where man's activities (unit 9) may have adversely affected a forest cover and consequently reduced any potential bank reinforcement caused by the forest roots. The river, however, has eroded the bank to a depth well below that where roots are found. Along reach 1, this depth can be 32 ft below the ground surface, and 8 to 15 ft below along reach 2 (Fig. 8).

I suggest that falling trees may actually contribute to bankline recession. Once the supporting sediment below the tree root zone is eroded, the unsupported trees would lean and collapse into the river, carrying with them large amounts of bank sediment. Since the white spruce/paper birch trees in unit 2 may be older (Table 1) and have a more developed root system than the trees in the other units, they may remove more bank sediment when they col-

Table 6. Bankline recession (ft) along transects drawn from each well through the historical banklines, reach 2 (Fig. 4).

Wells	1948-1961		1961-1970		1970-1975		1975-1980	
	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative
653	0	0	0	0	0	0	0	0
651	0	0	240	240	240	480	180	660
33	200	200	280	480	100	580	40	620
34	410	410	0	410	0	410	140	550
35	0	0	100	100	60	160	0	160
36	0	0	0	0	100	100	0	100
37	0	0	0	0	80	80	0	80
124	80	80	0	80	260	340	0	340
39	60	60	310	370	150	520	0	520
40	30	30	50	80	150	230	0	230
41	0	0	0	0	260	260	0	260
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
	Avg=60		Avg=80		Avg=110		Avg=30	

Table 5). The average recession in unit 4 was 390 ft (the high being 620 ft, the low, 0 ft) and the average in unit 15 was 240 ft (the high being 520 ft, the low 80 ft). No bank recession occurred in unit 9. This finding suggests that the bank with unit 2 vegetation is most erodible, followed by the banks with units 4, 15 or 9 in decreasing order.

With minor exceptions, the trends in the bankline recession have not changed drastically during any of the intervals (Fig. 7). The western end of the reach (Fig. 4) receded faster in each interval than the middle or eastern portions. However, interval recession varied drastically (Table 6) adjacent to particular wells and within the same vegetation unit.

From 1961 to 1970, high recession occurred in units 15, 4 and 2 while most of the recession was in unit 15. From 1970 to 1975, most recession occurred in unit 15 and less in units 2 and 4. From 1975 to 1980, most recession occurred in units 4 and 2 vegetation, while units 15, 9 and 4 showed no recession.

Discussion. Although the amounts and the time of recession for a particular vegetation unit vary greatly, the cumulative recession data along both reaches suggest that banks with unit 2 vegetation receded the most and those with unit 9 vegetation receded the least (Table 3). This is contrary to what is frequently assumed. Investigators report that vegetation reinforces bank sediments (Smith 1976) and contributes to bank resistance (Mackin 1956). The binding from the vegetation root mat can retard slumping of undercut banks but is unimportant in limiting bank erosion along large streams (Scott 1978). One would expect less erosion along banks with extensive tree root systems

Table 5. Bank characteristics at well locations, reach 2.

					Sediments							
						Site-specific (%)*						
Well no.	Eroded	Cumulative recession (ft)	Vegetation	Soils	General	PT	ML	SM	SP	GP	GW	Permafrost
653	No	0	—	---	Qc					100		No
651	No	660	2	Sc	Qc		41		59			No
33	No	620	4	Sc	Qc	16	44	30	10			No
34	No	550	4	Ta	Qc	20	45	25	10			No
35	No	160	15	Ta	Qc	16	49	25	10			No
36	No	100	15	Sc	Qc	16	54	24	6			No
37	No	80	15	Ta	Qc	24	50	26				No
124	Yes	340	15	Sc	Qc	22	28				50	No
39	No	520	15	Sc	Qc	18	56	18		8		No
40	No	230	15	Sc	Qc	20	56	24				No
41	No	260	15	Sc	Qc	20	50	30				No
42	No	0	4	Sc	Qc	16	48	36				No
43	No	0	9	Sc	Qc		50	30	20			No

* Sediment percentages from top of bank to 18-ft depth.

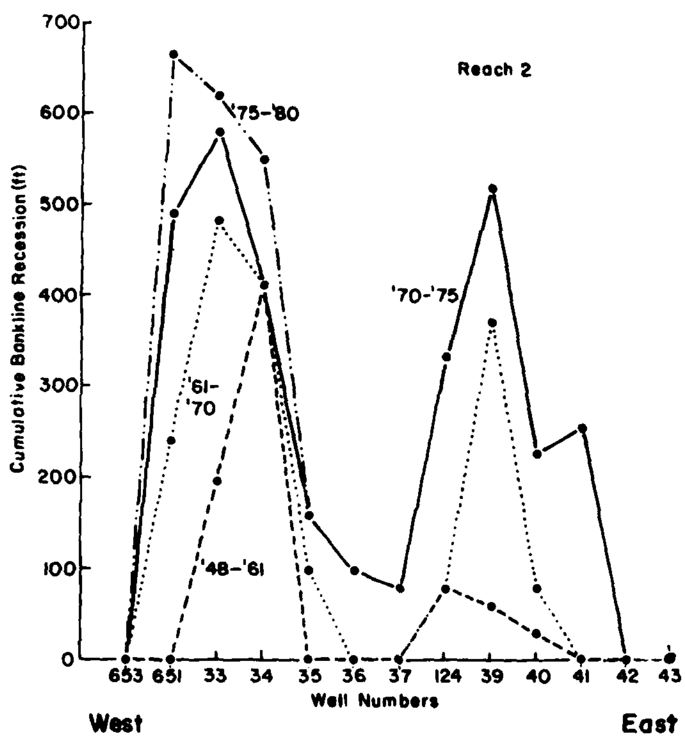


Figure 7. Bankline recession adjacent to the wells along reach 2.

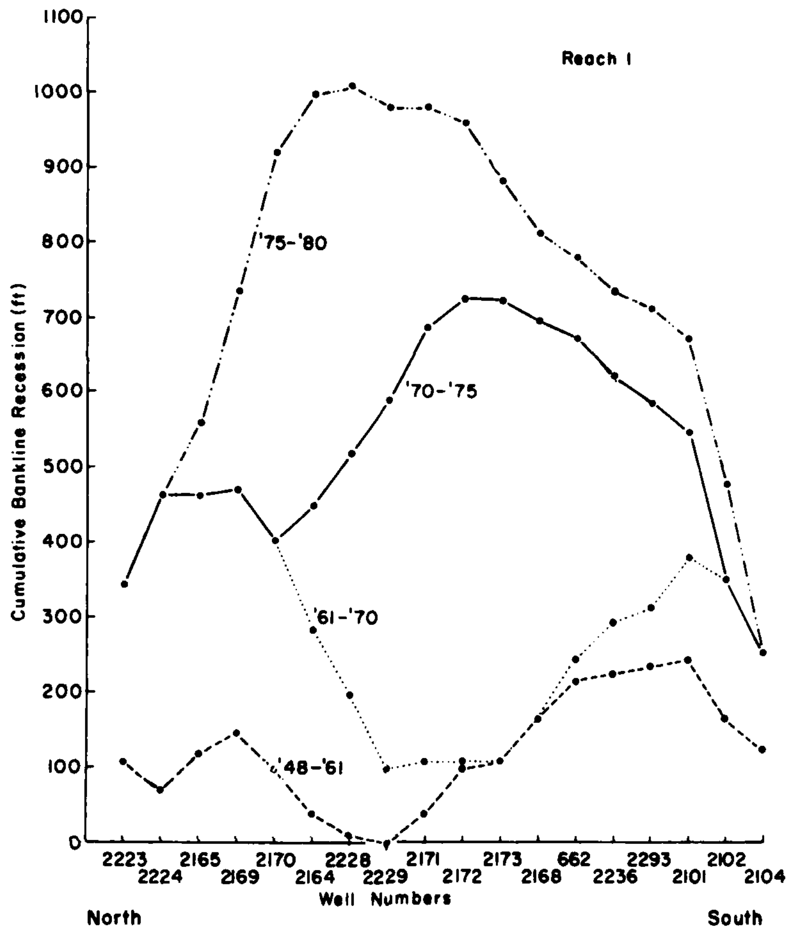


Figure 6. Bankline recession adjacent to the wells along reach 1.

and 5. From 1975 to 1980 more of the bank with unit 2 vegetation receded faster than the portion with units 5 and 9, respectively (Table 4).

Reach 2. Most of reach 2 (Fig. 5) is covered by balsam poplar/white spruce (unit 15), followed by balsam poplar/paper birch (unit 4) and white spruce/paper birch (unit 2). Less unit 2 vegetation appears to be within the eroded area of reach 2 than within that of reach 1. "Water and cultural features" (unit 9) cover only a small part of the reach on the eastern end. The vegetation at well site 653 was not mapped (Table 5). One well was in units 2 and 9, three wells were in unit 4, and seven wells were in unit 15.

With the first method, it would be inferred that unit 15 vegetation is the most erodible along reach 2 because the only eroded well was in unit 15. The other units would be equally less erodible (Table 3). With the transect method, the highest cumulative recession (660 ft) occurred in unit 2 (Fig. 7;

Table 3. Summarized results of vegetation analysis.

Analytical methods	Reach 1	Reach 2
Method 1	unit 2,9,5	unit 15, 4&2&9
Method 2		
Cumulative recession	unit 2,5 or 9	unit 2,4,15,9
Recession per Interval		
1948-1961	unit 5,9,2	no data
1961-1970	unit 9&2,5,5&2	unit 15,4&2,15,15&14&9
1970-1975	unit 5,2&5,9&2&5	unit 15,2,4,4&9
1975-1980	unit 2,5,9	unit 2,4,9,15

Measured recession (method 2) decreased in units as listed.

Table 4. Bankline recession (ft) measured along transects drawn from each well through the historical banklines, reach 1 (Fig. 4).

	1948-1961		1961-1970		1970-1975		1975-1980	
Wells	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative
2223	110	110	240	350	0	350	0	350
2224	70	70	390	460	0	460	0	460
2165	120	120	340	460	0	460	100	560
2169	150	150	320	470	0	470	260	730
2170	100	100	300	400	0	400	520	920
2164	40	40	240	280	170	450	550	1000
2228	10	10	190	200	320	520	490	1010
2229	0	0	100	100	490	590	390	980
2171	40	40	70	110	580	690	290	980
2172	100	100	10	110	620	730	240	970
2173	110	110	0	110	620	730	160	890
2168	170	170	0	170	530	700	120	820
662	220	220	30	250	430	680	110	790
2236	230	230	70	300	320	620	110	730
2293	240	240	80	320	270	590	130	720
2101	240	240	140	280	170	550	130	680
2102	170	170	190	360	0	360	130	490
2104	130	130	130	260	0	260	0	260
	Avg=130		Avg=160		Avg=250		Avg.=210	

unit 5 with 970 ft and 700 ft, respectively, and unit 9 with 560 ft and 460 ft, respectively. However, unit 5 also had the lowest cumulative recession, 260 ft. These cumulative figures suggest that unit 2 is most erodible, followed by either units 5 or 9. However, the amounts of bankline recession along a transect change between the time intervals (Fig. 6) so that the effects of vegetation do not always influence bank erosion in the same way and the same bank erodes at variable rates.

From 1948 to 1961 most recession (Fig. 6; Table 4) occurred where unit 5 vegetation predominates and the least recession occurred in unit 2 vegetation. From 1961 to 1970, most recession occurred in unit 9 and 2 vegetation and less recession occurred in units 5 and 2. From 1970 to 1975, most recession occurred in unit 5 vegetation and there was no recession in units 9, 2

Table 2. Bank characteristics at well locations, reach 1.

Well no.	Eroded	Cumulative recession (ft)	Vegetation (unit no.)	Soils	Sediments												Permafrost (depth interval, ft)
					General	Site specific (%)*											
						PT	PT/OL	OL	OL/ML	ML	SM	SP	SP/SM	GM	GP	GP/GM	
2223	No	350	9	Ta	Q_c	1.5						80			18.5		No
2224	No	460	9	Ta	Q_{cs}	1.5			2	42				4.5	50		0–1.5†
2165	Yes	560	9	Ta	Q_c			3.5		23.5	16	6.5				50.5	0–1†
2169	Yes	730	2	Ta	Q_c			2.5		15	25.5	26.5	30.5				0–1.5†
2170	Yes	920	2	Br	Q_c			4.5		40	55.5						0–1.5†
2164	Yes	1000	2	Br	Q_{cs}			5		8.5	16	11	18.5		41		0–1†
2228	Yes	1010	2	Br	Q_{cs}	.5	6				28.5				65		0–2.5†
2229	Yes	980	2	Br	Q_c	1.5				6.5	10	16.5			65.5		0–13
2171	Yes	980	2	Ta	Q_c			1.5		31.5	7	47.5		12.5			0–28
2172	No	960	5	Ta	Q_c			2.5		37.5				30	30		0–.5† 2.5–14
2173	No	890	5	Ta	Q_c	1.5				17.5	63.5	17.5					No
2168	No	820	5	Ta	Q_{cs}			3.5		15.5		6.5	61	13.5			0–1† 28–50
662	No	790	5	Ta	Q_c					13.5		86.5					No
2236	No	730	5	Br	Q_c					3.5	55				41.5		0–2.5†
2293	No	720	5	Br	Q_{cs}			3.5		78.5	18						3–15
2101	Yes	680	5	Br	Q_c	3.5				96.5							3–15
2102	No	490	5	Br	Q_c	3.5				56.5	20		20				2.5–15
2104	No	260	5	Ta	Q_c	2.5		17.5		15	35	10			20		2.5–20

* Sediment percentages from top of bank to 32-ft depth.
† Probably seasonal frost; drilled in the winter.

Table 1. General characteristics of locales along the Tanana River that have the vegetation shown (from Van Cleve et al. 1980).

Age (yr)	Elevation	Frequency of flooding	Vegetation type	Effects of alluvial erosion and deposition and other physical controls	% Shrub cover
2-5 (newly-deposited alluvium)			Open shrub (willow/alder)		0-35
5-10			Closed shrub		35-55
20-40			Young balsam poplar		10-100
80-100	Increasing	Decreasing	Mature balsam poplar, Young white or black spruce, Alder	Decreasing	30-50
125-175			Old balsam poplar, Young white or black spruce		10-50
200-300 (old Alluvium)			Mature white or black spruce		10-20

where paper birch predominates is similar to that where white spruce is found.

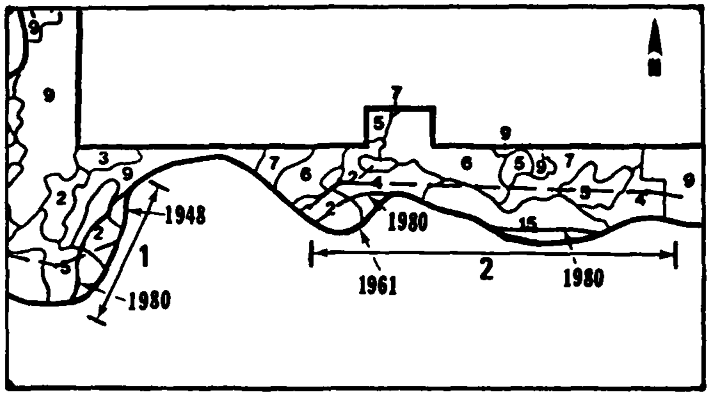
Reach 1. White spruce/paper birch (unit 2) and paper birch/black spruce (unit 5) covered most of the land area along reach 1 that was eroded between 1948 and 1980 (Fig. 5). The north part of the reach was predominantly water and cultural features (unit 9). Three well sites are in unit 9 (Table 2), six in unit 2 and nine in unit 5.

Using the first analytical method, I estimated that one of the three wells in unit 9, all six in unit 2, and one of the nine in unit 5 were eroded between 1948 and 1980. From these figures, it can be inferred that the section with unit 2 vegetation is most erodible and that the sections with units 9 and 5 follow in decreasing order (Table 3).

Wuebben[2] pointed out that the amount of historical recession adjacent to the eroded well locations and the uneroded locations is nearly equal (Fig. 4). The recession for these two groups has occurred during different times as the river migrated and eroded different parts of the bank. The uneroded well locations (Fig. 4) are simply farther back from the 1980 bankline.

Following the second (or transect) method, the highest cumulative (1010 ft) and average (940 ft) recession occurred in unit 2 (Table 2), followed by

[2] J. Wuebben, CRREL, pers. comm. 1982.



2 - White spruce/paper birch
4 - Balsam poplar/paper birch
5 - Paper birch/black spruce (usually a wetland)
9 - Water and cultural features
15 - Balsam poplar/white spruce

Figure 5. Vegetation distribution (Graham 1975); bankline position similar to that in 1984 along reach 1 (Fig. 4) and 1961 along reach 2 (Fig. 4).

more recent information would likely be more reliable because fires in the Tanana River lowlands frequently alter the natural succession of trees. In addition, the Graham map contained more vegetation units for reach 2, which allowed a better evaluation of erosion differences between the units.

The Graham (1975) vegetation units (Fig. 5) are so general that only four tree types make up the four units. The vegetation in unit 9 was not given but it is probably similar to the others. Paper birch is in three units, while white spruce and balsam poplar are in two. This overlap complicates trying to infer if vegetation has affected erosion along these reaches.

Unit 2 is dominated by white spruce stands with secondary paper birch. The age of the white spruce trees could vary from 80 to 300 years (Table 1). Usually the elevation of the area with white spruce above the river is higher than with other trees. Consequently, the frequency of floods, fluvial effects, and the percentage of shrub cover decrease with age.

Balsam poplar dominates in units 4 and 15. Generally the age would vary between 20 and 175 years. The elevation of the terrain would be lower than that with white spruce and would tend to be affected more by flooding and other fluvial actions. Also the shrub cover is more extensive (10% to 100%).

Paper birch dominates unit 5, which is usually a wetland. Frequently, paper birch succeeds after white spruce has been burned, so that the area

data. Two methods were used for evaluating the correlation between vegetation, soils, sediment and permafrost and riverbank erosion.

Method 1. The first method was to visually compare the vegetation, soils, sediments and permafrost data to detect any difference at eroded and uneroded well sites. There were two problems with this approach. First, the inaccurate positioning of the well sites with the zoom transfer scope influenced whether or not a well was positioned in the eroded or uneroded part of the bank (Fig. 4). This was a special problem where the wells were originally drilled near an old riverbank or where the wells are now near the bank due to bankline recession.

Second, it was not possible to determine whether a particular well location was eroded because of its vegetation, soil, sediment or permafrost characteristics or simply because it was drilled nearer the bank than an uneroded well. To adequately evaluate if bank erosion could be related to the available data, I eliminated this uncertainty by the second method.

Method 2. This second approach gave a measure of erodibility of the bank as a function of estimated bank recession and not well location. This approach used the well logs only to give profiles of bank sediments and permafrost. I had to assume for this method that the bank sediment and permafrost profile for a well was the same along an entire transect drawn through the well. The actual ground locations of the wells relative to the bankline were not important in this approach.

Transects were drawn perpendicularly to the historical banklines through the well sites, and the amount of bank recession for the historical periods was measured along these transects. Then I compared the bank characteristics to differences in measured recession. Although possible correlations can be more reliably evaluated with this second method, results from both methods are discussed for comparison so that inferences gained from either approach will not be overlooked.

RESULTS

Vegetation

Vegetation information was available from maps and descriptions by Graham (1975) and Rieger et al. (1963). Information from the latter source was based on photointerpretation of 1951 photography. Haugen[1] suggested that the

[1]R. Haugen, CRREL, pers. comm. 1982.

d. Eastern part of reach 2.

Figure 4 (cont'd). Approximate historical bankline positions (from Buska 1981) and well and river cross-section locations (photographs taken 7 May 1980; 1:5000 scale).

c. Middle part of reach; note the USGS gauging station.

Figure 4 (cont'd).

b. Western part of reach 2.

Figure 4 (cont'd). Approximate historical bankline positions (from Buska 1981) and well and river cross-section locations (photographs taken 7 May 1980; 1:5000 scale).

a. Reach 1, note revetment shown in Figure 2.

Figure 4. Approximate historical bankline positions (from Buska 1981) and well and river cross-section locations (photographs taken 7 May 1980; 1:5000 scale).

lapse into the river. However, Wuebben[3] points out that bank erosion caused by collapsing trees may only be a local, temporary aberration. Since the bank was probably receding anyway, collapsing trees would remove soils only from the top of a bank and would dislodge a minor amount of extra soil. Along a forested bank, more significant bank soil removal and bankline recession might occur where many trees are collapsing frequently.

Chacho[4] agrees that the amount of bank sediment dislodged when trees fall would probably be insignificant. He suggests that the collapsed trees may protect the bank because they can frequently remain attached to the bank and lie against its submerged portion. As long as the trees remain attached, whether on the water surface or submerged, it could be argued that the bank is protected from river erosion because the currents are diverted from the bank and the current velocity near the bank is reduced. The protection offered by slumped vegetation has also been discussed by others (Scott 1978, Klimek 1975, Smith 1976, Miles 1977).

The comparisons between the measured recession and vegetation in the intervals gave inconsistent results. The bank along reach 1 with unit 5 vegetation receded the most during two intervals, and the least during two. Banks with unit 9 receded most during one interval and the least during two. Banks with unit 2 receded most during one interval and the least during three.

Along reach 2, banks with unit 15 vegetation receded the most during two intervals and the least during three. Banks with unit 4 receded most during one interval and the least during three. Banks with unit 2 receded most during one and the least during one.

In light of the inconclusive evidence from this analysis and the speculations on the effects that trees may have on bank stability, it is impossible to adequately infer where future bank erosion will occur from the distribution of vegetation types available on the existing maps. From my experience, I think this type of simple correlation is not valid without additional data. The influences of vegetation on bank erosion are neither simple nor consistent and many other factors may affect the amount of erosion that occurs at a location.

The results suggest that either the vegetation has little effect on the erodibility of the bank or the existing data on vegetation are not detailed

[3] J. Wuebben, CRREL, pers. comm. 1982.
[4] E. Chacho, CRREL, pers. comm. 1982.

enough to be useful in determining possible vegetative effects. In my opinion vegetation is not an important factor influencing bank erosion along the Tanana River.

Soils

The regional soil association along both reaches is loamy, consisting of nearly level histic pergelic cryaquepts[5] and typic cryofluvents[6] (Rieger et al. 1979). Along the lower parts of the floodplain, soils are poorly drained with permafrost. Soils on natural levees are well drained, with permafrost deep or absent. Due to extensive channel shifting, abandoned channels are numerous but not always conspicuous. Most areas of this association are flooded occasionally.

The histic pergelic cryaquepts occur in poorly drained, low areas such as meander scars. They have thick surface organic horizons and are usually saturated above a shallow permafrost table. These soils are usually stratified and range from silt to sandy loam. The typic cryofluvents occur on natural levees and are well-drained, having thin organic seams throughout and permafrost at 5 ft or more. Usually, they consist of stratified silt loam and fine sands, but some have uniform textures.

Three soil series were present along the two reaches, Salchaket (Sc), Bradway (Br) and Tanana (Ta) (Fig. 9). Characteristics of these soils are summarized in Table 7 and an idealized distribution of soils across the Tanana River floodplain is shown in Figure 10.

The differences between sediment textures and some of the characteristics of the three soil series (Table 7) are insignificant. One would not expect a substantial difference in their erodibility. The Salchaket and Tanana soils form in similar locations and all three have sands and silts of variable thicknesses over gravels. Their profiles are similar: organics over silt loam over fine sand. The Salchaket soil typically has gravels beneath 2 ft. Drainage in the Salchaket is good, but poor in the Bradway and Tanana. The wetter Bradway and Tanana soils may be slightly more erodible due to

[5]Typic cryofluvents: mostly gray soils with alternating layers of sand and silt loam, usually underlain by thick very gravelly sand; some irregular black and brown streaks from buried organics; free of permafrost or only at great depth; usually occupy natural levees.

[6]Histic pergelic cryaquepts: soils with texture ranging from gravelly sand to clay, color from gray to olive grey, thick organic matter on surface; permafrost is shallow and active layer is saturated when thawed; textural soil layers are disrupted by freeze-thaw and frost processes; occur in lowlands and hilly areas.

a. Reach 1.

b. Reach 2.

Figure 9. Soil series (from Rieger et al. 1963). The bankline is as shown in 1951 photography and is similar to that in 1948 (Fig. 4a). For purposes of this analysis, the two banklines were considered the same.

Table 7. Soil series characteristics (from Rieger et al. 1963, 1979).

Series	Classification	Texture	Location/Surface Features/ Topographic Position
Salchaket (Sc, very fine sandy loam)	Family: Coarse-loamy, mixed, nonacid Subgroup: Typic cryofluvents Order: Entisols Great Group*:	- Sandy with silty layers - Underlain by coarse sands and gravels at 10 in. to 6 ft or more - thin silt layers or coarse sand seams at any depth - Silty surface layer absent locally, but may be up to 12 in thick	Developed in nearly level, recently deposited water-laid material; surface dissected locally by sloughs and old stream scars; contains strips of Bradway very fine sandy loam too narrow to map separately
Bradway (Br, very fine sandy loam)	Family: Loamy, mixed, nonacid Subgroup: Pergelic cryaquepts Order: Inceptisols Great Group: Low-humic gley soils	- Sandy - Gravel underlies at 4 ft or more	Usually in former stream channels (from less than 10 ft to more than a mile wide); narrow channels near Tanana River subject to flooding; lower topographic position than Slachaket soils; nearly level terrain
Tanana (Ta, silt loam)	Family: Loamy, mixed, nonacid Subgroup: Pergelic cryaquepts Order: Inceptisols Great Group: Low-humic gley soils interfacing toward alluvial soil	- Silty - lenses of very fine sandy loam or fine sand common at any depth - gravel at 4 to 10 ft	Nearly level terrain developed in silty material usually located farther from principal streams than the Salchaket soils

*1938 classification

Table 7 (cont'd).

Typical Profile (inches)	Drainage	Vegetation	Permafrost
7-0: mat of roots, moss, org. mat'l; very acid 0-3: (ML)** olive brown/greyish-brown silt loam with lenses of org. mat'l; weak granular structure; very friable; very acid 3-10: (ML) gray/brown very fine sandy loam very weak blocky structure; very friable; slightly acid 10-26: (SM or ML) gray fine sand mottled broen; no structure; loose; weak alkaline 26 +: (GP or SP) gravel/coarse sand; rounded pebbles	Well-drained; seasonal high water table, 10-15 ft	White spruce, paper birch, quaking aspen some balsam poplar	Usually absent in soil above gravel Silty lenses under vegetation may stay frozen into summer
4-0: mat of organic mat'l mixed with small amounts of silt, medium acid; may be 12 in. thick locally 0-2: (OL) black, mucky silt loam; weak granular structure; friable; slightly acid 2-36: (ML) dark-grey very fine sandy loam mottled dark brown; weak platy structure: very friable; mildly alkaline; thin lenses of silt and fine sand, usually below 24 in.; may be greenish or bluish in lower part	Poorly drained; usually always wet above permafrost; seasonal high water table usually 18 in.	Dense stand of sedges and grasses to low shrubs and clumps of black spruce	Present below 3-4 ft under native vegetation
5-0: mat of roots, moss, lichens; dark brown surface to black at bottom; very acid 0-4: (MH, OH or OL) olive-grey silt loam with patches of black and gray brown; massive; friable; neutral pH 4-20: (ML) olive-brown silt loam with patches of black and gray brown and dark brown mottles; massive; friable; mildly	Imperfectly drained; always wet above permafrost; seasonal high water table, less than 1 ft	Scrubby black and white spruce, paper birch, tamarack and willow; mat of moss and low shrubs below trees	Present at 30 in. or less under native vegetation

**Equivalent classification in the USCS

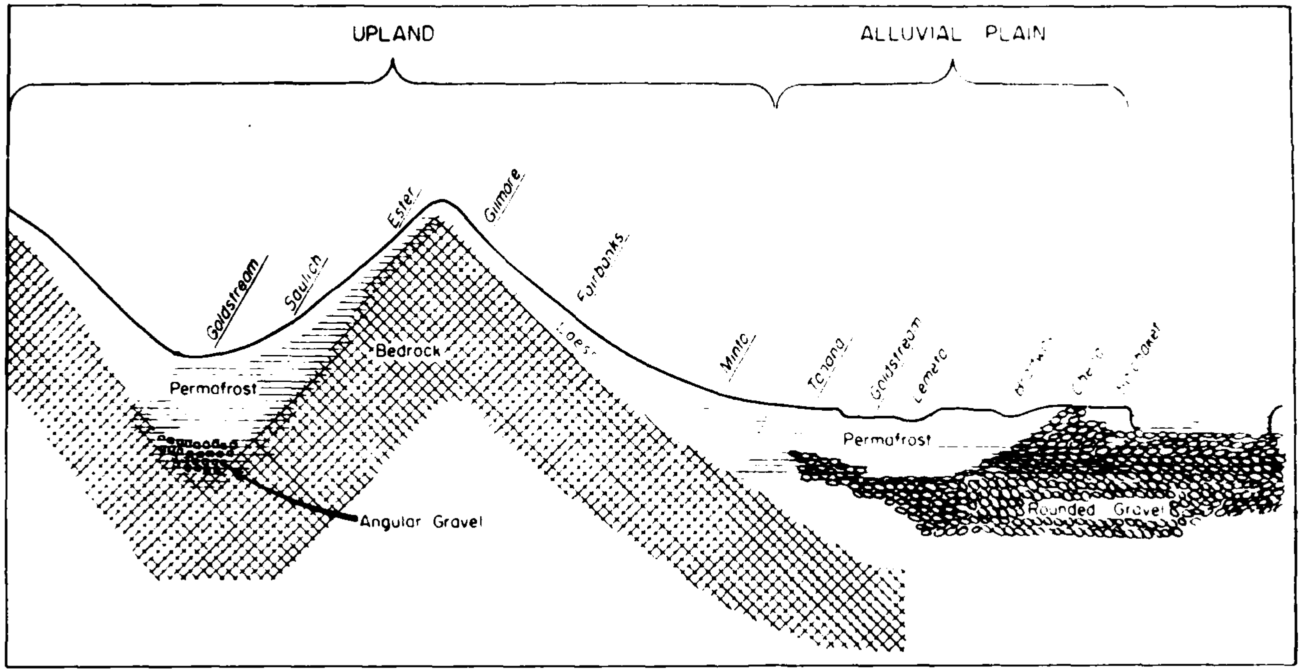


Figure 10. Generalized landscape showing relative distributions of soil series, underlying material and permafrost (from Rieger et al. 1963).

their more persistent wetness. Permafrost is usually absent in the Salchaket above the gravels, but the Bradway and Tanana have permafrost at 3-4 ft and at about 30 in., respectively.

Reach 1. Ten wells are located in the Tanana soil and eight in the Bradway (Table 2). Three of the eight eroded sites were in Tanana soil and five were in Bradway. Seven of the 10 uneroded sites were in Tanana soil and three of 10 were in Bradway (Table 8). This trend suggests that the Bradway soil is more erodible. But as previously stated, this first method of simply comparing soils at eroded and uneroded well sites may not a reliable way to

Table 8. Summarized results of soils analysis.

Analytical method	Reach 1		Reach 2	
Method 1				
Eroded wells	5 of 8	(62%)-Br	1 of 1	(100%)-Sc
	3 of 8	(38%)-Ta		
Uneroded wells	7 of 10	(70%)-Ta	8 of 11	(73%)-Sc
	3 of 10	(30%)-Br	3 of 11	(27%)-Ta
Method 2				
Cumulative recession*	9 of 13	(69%)-Br	3 of 4	(75%)-Sc
	4 of 13	(31%)-Ta	1 of 4	(25%)-Ta
Cumulative recession†	4 of 5	(80%)-Ta	6 of 8	(75%)-Sc
	1 of 5	(20%)-Br	2 of 8	(25%)-Ta
Transects with most recession				
1951(1948)-1961	4 of 6	(67%)-Br	1 of 2	(50%)-Sc
			1 of 2	(50%)-Ta
1961-1970	4 of 7	(57%)-Ta	2 of 3	(66%)-Sc
1970-1975	4 of 6	(67%)-Br	4 of 4	(100%)-Sc
1975-1980	5 of 7	(71%)-Br	2 of 3	(66%)-Sc
Transects with highest recession				
1951(1948)-1961	Ta		Ta	
1961-1970	Br		Sc	
1970-1975	Br		Sc	
1975-1980	Br		Sc	
Transects with lowest recession				
1951(1948)-1961	Br		5 of 8	(63%)-Sc
			2 of 8	(25%)-Ta
1961-1970	Br		5 of 8	(63%)-Sc
			2 of 8	(25%)-Ta
1970-1975	6 of 7	(86%)-Ta	2 of 4	(50%)-Ta
	1 of 7	(14%)-Br	1 of 4	(25%)-Ta
1975-1980	Ta		7 of 10	(70%)-Sc
			2 of 10	(20%)-Ta
Dominant soil per interval				
1951(1948)-1961	10 of 17	(59%)-Br	4 of 5	(80%)-Sc
	5 of 17	(29%)-Ta	1 of 5	(20%)-Ta
	2 of 17	(12%)-Sc		
1961-1970	9 of 16	(56%)-Br	4 of 5	(80%)-Sc
	7 of 16	(44%)-Ta	1 of 5	(20%)-Ta
1970-1975	8 of 11	(73%)-Br	7 of 9	(78%)-Sc
	3 of 11	(27%)-Ta	2 of 9	(22%)-Ta
1975-1980	9 of 15	(60%)-Ta	2 of 3	(66%)-Sc
	6 of 15	(40%)-Br	1 of 3	(34%)-Ta

* > 600 ft, reach 1; > 400 ft, reach 2
† < 600 ft, reach 1; < 400 ft, reach 2

Table 9. Soils eroded and amount of recession per interval, reach 1.

Well	1951(1948)-1961		1961-1970		1970-1975		1975-1980	
Number	Soils*	Recession (ft)†	Soils*	Recession (ft)†	Soils*	Recession (ft)†	Soils*	Recession (ft)†
2223	Sc,Ta	110	Ta	240	Ta	0	Ta	0
2224	Sc	70	Br	390	Ta	0	Ta	0
2165	Br	120	Ta,Br	340	Ta	0	Ta	100
2169	Ta,Br	150	Ta,Br	320	Ta	0	Ta	260
2170	Ta,Br	100	Ta,Br	300	Br	0	Ta,Br	520
2164	Br	40	Br,Ta	240	Br,Ta	170	Br	550
2228	Br	10	Br	190	Br	320	Br	490
2229	Br	0	Ta	100	Ta,Br	490	Br	390
2171	Br	40	Br,Ta	70	Ta,Br	580	Br,Ta	290
2172	Br	100	Br	10	Br	620	Br,Ta	240
2173	Br	110	Br	0	Br	620	Ta,Br	160
2168	Br	170	Br	0	Br,Ta	530	Ta,Br	120
662	Br	220	Br	30	Br,Ta	430	Ta,Br	110
2236	Br	230	Br	70	Ta,Br	320	Ta,Br	110
2293	Br	240	Br	80	Br,Ta	270	Ta,Br	130
2101	Ta,Br	240	Br	140	Br	170	Br	130
2102	Ta	170	Ta	190	Ta	0	Ta,Br	130
2104	Ta	130	Ta	130	Ta	0	Ta	0
		Avg = 130		Avg = 160		Avg = 250		Avg = 210

* Soil series eroded the most in an interval is listed first.
† From Table 4.

evaluate the erodibility of a bank with a particular soil. This is especially true when the soil distribution between the 1951 and 1980 banklines is as complex as it was along reach 1 (Fig. 9a). Clearly, different soils were being eroded during the intervals.

The following observations were made from the second method. The Bradway soil was the most frequently eroded (Table 9) along six of the eight transects where the cumulative recession was greater than 800 ft, while Tanana soil predominated along two of the eight (Table 4). Where 600 to 800 ft of cumulative recession was found, Bradway predominated along three of five transects and Tanana along two. Along the five transects with less than 600 ft cumulative recession, Tanana predominated along four and Bradway along one. Within these three recession ranges Bradway soil predominated along nine of 13 transects with more than 600 ft recession and Tanana predominated along four of 13. This suggests that banks with Bradway soil are more erodible.

When soils and recession within each historical interval are analyzed, a more complex and inconsistent picture results. From 1951 to 1961, average recession was 130 ft and Bradway soil predominated along 11 transects, Tanana along five and Salchaket along two (Table 9), yet the lowest recession occurred in Bradway soil and the highest in Tanana and Bradway soils. From 1961 to 1970, average recession was 160 ft (Table 9) and Bradway soil predom-

inated along nine transects and Tanana along seven, yet the highest and lowest recession also occurred in Bradway soil. From 1970 to 1975, average recession was 250 ft and Bradway soil predominated along eight transects, and Tanana along three. The highest recession occurred in Bradway soil and no recession occurred along seven transects while Tanana soil predominated. From 1975 to 1980, average recession was 210 ft (Table 9) and Tanana soil predominated along nine transects, and Bradway along six. The highest recession occurred in Bradway soil and no recession occurred along three transects with Tanana soil.

Reach 2. The soil distribution along reach 2 (Fig. 9b) in the zone eroded between 1951 and 1980 is not as complex as it was along reach 1 (Fig. 9a). The Salchaket soil covered most of this zone, although Tanana soil covered a small central area. Nine wells were drilled in Salchaket soil (Table 5) and three in Tanana. None of the well sites in Tanana soil was eroded, while only one of nine sites (well 124) in the Salchaket soil was eroded. These results from the first method suggest that neither soil is appreciably more erodible than the other.

The following observations were made from the second method. Salchaket soil was eroded along the two transects where the cumulative recession was greater than 600 ft (Table 5). At areas with between 400 and 600 ft of cumulative recession, Tanana soil was eroded along one of two transects and Salchaket along one of two. Along the eight transects with less than 400 ft of recession, Salchaket occurred along six and Tanana along two. Since Salchaket soil occurs along seven of the 10 eroded transects (Table 5), both high and low cumulative recession occur in Salchaket soil only because it is more common along reach 2. Recession during the four intervals also shows inconclusive results.

From 1951 to 1961, average recession was 60 ft (Table 6) and most of the recession occurred in Salchaket soil (Tables 5 and 6) while five transects with Salchaket soil had no recession. The highest recession occurred in Tanana soil. From 1961 to 1970, average recession was 80 ft and the most recession for this time period and the highest recession occurred in Salchaket soil, while five transects in Salchaket soil had no recession. From 1970 to 1975, average recession was 110 ft and Salchaket soil occurred where the most and the highest recession occurred. Salchaket soil also occurred where there was no recession. From 1975 to 1980, average recession was 30 ft. The highest recession and those transects with no recession were in Salchaket soil.

Discussion. Most recession along reach 2 occurred in Salchaket soil, but recession along reach 1 was primarily in Bradway. Bank recession was lowest along reach 1 where Salchaket soil occurred and along reach 2 where Tanana occurred. The average recession along reach 1 per interval was much higher than along reach 2, which suggests that the Bradway and Tanana soils along reach 1 are more erodible than the Salchaket and Tanana soils along reach 2. However, this apparent relationship is not straightforward.

The main portion of river flow shifts (Figs. 4 and 9) and different soils were eroded at different rates during the intervals. There does not appear to be a preferential trend controlled by soil distribution. It may be that the soil most eroded along a reach is simply that which is most common in the area. Clearly the Bradway (reach 1) and Salchaket soils (reach 2) are most common.

Most of the eroded wells and the highest cumulative recession (Table 8) along reach 1 were in Bradway soil. The group of transects where the most recession occurred per interval was also in Bradway soil for three of the four intervals. Likewise, the highest recession per transect occurred where Bradway soil was dominant in three of the four intervals (Table 8). However, Bradway soil also occurred along transects where the lowest recession per interval was measured.

Along reach 2 Salchaket soil is most common and occurs in the only eroded well. It is also predominant in the uneroded wells and along transects where the cumulative and per interval recession are highest and lowest. Nothing conclusive can be stated from these observations. It is probably true that Salchaket soil is most frequently eroded along reach 2 only because it is most common, not because it is more erodible.

In addition, the portion of the bank eroded by the river includes more than just the upper few feet where the soils have formed. The river erodes the entire bank from the waterline to the bottom of the channel. As previously mentioned, the Tanana River can be 32 ft deep along reach 1 (Fig. 8).

On 6 October 1979 when cross section 4A was taken, the water surface was between 417 and 418 ft msl, equivalent to a discharge of approximately 17,000 cfs. The river stage and discharge are generally higher than these for five months of the year, from late April through September, and lower for seven months, from October to late April. Typically, in non-flood conditions, the high water level reaches about 423 ft msl when the summer discharge peaks be-

tween 70,000 and 80,000 cfs (Burrows et al. 1981). This peak period lasts for approximately two weeks.

The typical Bradway soil profile extends to only 3 ft (Table 7). So normally the river water level reaches the lower 1 to 2 ft of the Bradway soil profile for about two weeks of the year. During the rest of the year, the river water erodes the 29 ft of the bank below the Bradway soil.

Bradway soil may be more erodible than the Tanana or Salchaket soils and therefore erodes more rapidly during this two-week high water period. However, the evidence is insufficient to demonstrate a relationship between any of the three soil series and areas of erosion along these reaches. Consequently, I suspect that the soils do not significiantly influence the location or rate of bank erosion and bankline recession.

Sediments and permafrost

Data on sediments and permafrost were available from maps and from well logs. The map information was general and the log data were site-specific and more reliable in characterizing bank conditions. Consequently, I analyzed the site-specific well logs more thoroughly than the maps. However, as mentioned previously, the logs do not generally show the sediment and permafrost characteristics in the eroded zone unless the well site was eroded. I assumed that the well site data were representative of the sediments and permafrost along the transects through a well.

The Tanana River lowland was unglaciated but contains several hundred feet of glacially fed river silt, sand and gravel deposits called the Chena alluvium. The alluvium consists of well-stratified sands and gravels (Q_c) and swale and slough deposits (Q_{cs}) (Fig. 11). Since Illinoian time these deposits have been modified by alternating periods of deposition and erosion, with the formation and destruction of permafrost. The next three paragraphs, summarized from Péwé et al. (1976) and Péwé and Bell (1974, 1976a, b, c), give a brief description of the Tanana sediments in this area.

The Q_c sands and gravels are usually 10 to 400 ft thick, with well-stratified and unconsolidated sands in rounded gravels, 1/4 to 3 in. in diameter. Gray silts and clays, $\leq$ 15 ft thick, overlay the sands and gravels. Permafrost, 2 to 275 ft thick, occurs locally. Ice content of the permafrost is usually low and restricted to pore spaces and thin seams (<1/16 in.) in the silts and clays.

The Q_{cs} swale and slough deposits are poorly stratified, unconsolidated, angular to subrounded silts and silty sands usually less than 15 ft thick,

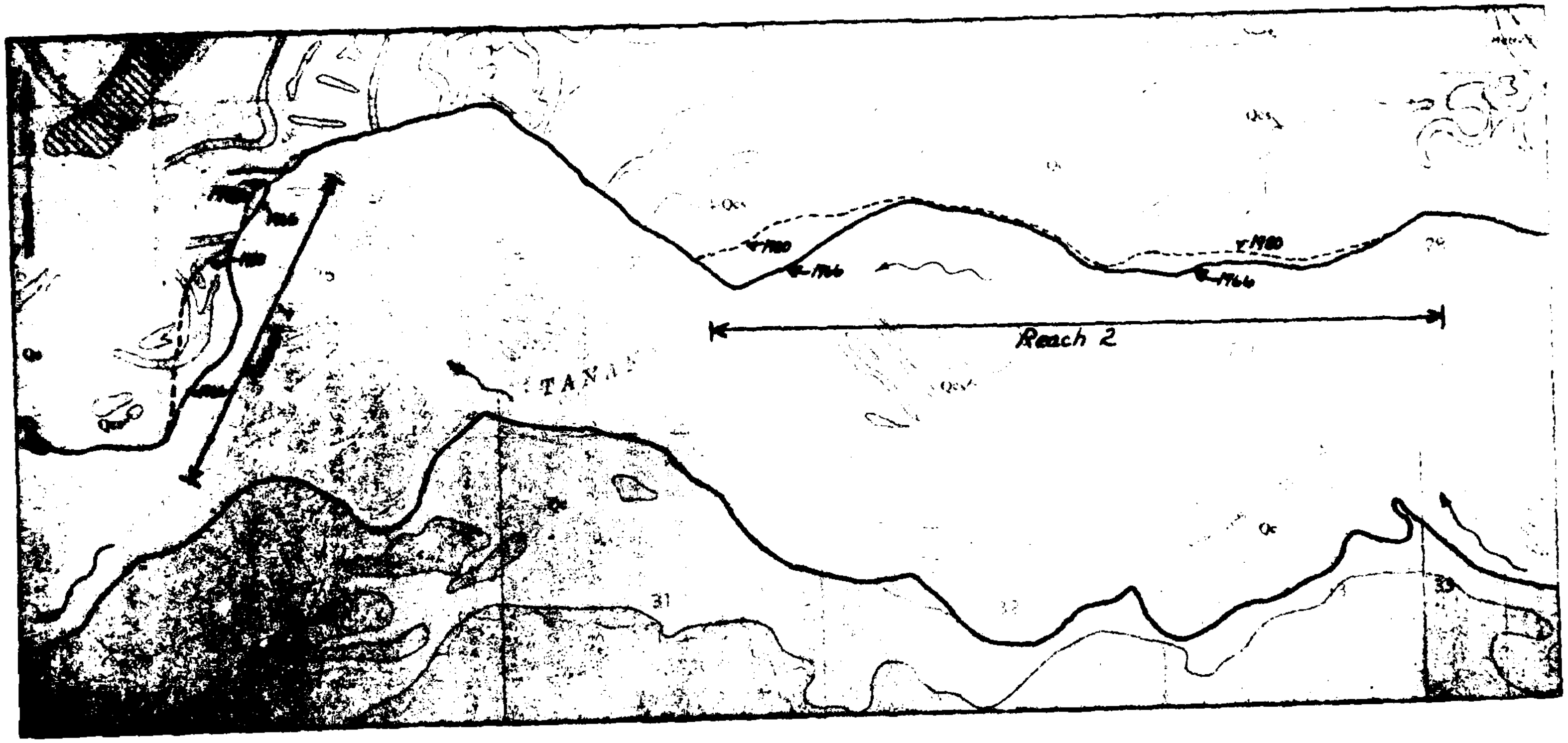


Figure 11. Distribution of the sands and gravels (Q_c) and swale and slough deposits (Q_{cs}) of the Chena alluvium (from Péwé et al. 1976). The bankline is as shown on 1966 photographs and is similar to that in 1970 (Fig. 4). For this analysis, the two banklines were considered the same.

although they are up to 30 ft locally. These silts and sands are fairly well sorted and contain organic material and 10 to 30% clay. Permafrost occurs locally with ice contents that vary from moderate, with ice restricted to pore spaces and seams 1/16 to >1/4 in. thick, to high, with large ice masses.

Other than the dominant sediment particle size and sediment layer thickness of the overlying the sands and gravels, there is little substantial difference between Q_c and Q_{cs}. Drainage is usually better in Q_c, but both are subject to flooding (Table 10). The depth of the permafrost is usually greater in Q_c and the seasonal frost layer is 2 to 9 ft thick. The depth of permafrost is 1.5 to 4 ft in Q_{cs}. The ice content in the permafrost is low to moderate in Q_c and moderate to high in Q_{cs}. The water table is 10 to 15 ft in both units. The silts of Q_c are moderately to highly susceptible to frost action, while Q_{cs} is highly susceptible. Both units have high bearing strength when frozen, but low strength when thawed. Thawed Q_c silts are poorly drained. Slopes in Q_c usually are steeper because Q_{cs} sediments slough and slide easily when thawed.

Reach 1. Sediments - General: Thirteen wells were drilled in Q_c and five in Q_{cs} (Table 2). Six of the eight eroded sites were in Q_c, while two were in Q_{cs} (Table 11). Seven of the 10 uneroded well sites were also in Q_c, and three were in Q_{cs}. These results are not conclusive. The percentages of wells eroded and uneroded in each unit are about equal. Possibly Q_c may be more common than Q_{cs} along reach 1 (see Fig. 11).

The following observations are based on the transect method of analysis. Q_c sediments were more common than, or equal to, Q_{cs} sediment along transects where cumulative recession was greater than 800 ft (Table 2), Q_c dominated along all transects with 600 to 800 ft of cumulative recession. The transects where recession was less than 600 ft were also through predominantly Q_c sediments. Thus these results are also inconclusive. The highest and lowest cumulative recession occurred where Q_c predominated. The results from the comparisons of recession by interval are no more definitive.

From 1966 to 1975, recession along 10 of 11 transects (Table 4) occurred in predominantly Q_c sediments (Figs. 4 and 11), no recession occurred along six transects where Q_c also predominated, and the highest recession occurred in Q_{cs} sediment. From 1975 to 1980, more erosion occurred along 11 of 15 transects in Q_c and four of 15 through Q_{cs} and no recession occurred along three transects also in Q_c. Thus these comparisons using Q_c and Q_{cs} data

Table 10. Engineering conditions and characteristics of Q_c and Q_{cs} deposits (from Péwé and Bell 1976b).

Map units	Terrain and natural slopes	Drainage and permeability	Permafrost	Susceptibility to frost action	Bearing strength and slope stability
Q_c	Flat plain with meandering streams and complex network of shallow swales	Drainage excellent and permeability high except locally in silt or where perennially frozen. Drainage improves with land clearing and lowering of permafrost table. Subject to flooding	Depth to permafrost 2-4 ft in older parts of flood plain and more than 4 ft on inside of meander curves near river. Depth to permafrost 25-40 ft in some cleared areas. Permafrost absent or deep beneath lakes, rivers, and creeks. Seasonal frost layer 2-9 ft thick. Permafrost 2-275 ft thick. Permafrost discontinuous unfrozen lenses, layers, and vertical zones. Low ground-ice content and mostly interstitial in sand and gravel, ice content low to moderate in top silt layer. Water *table 10-15 ft where permafrost absent or* deep	Silt, moderate to high; sand and gravel, unsusceptible	High bearing strength when frozen, sand and gravel high when thawed, silt moderate to high when thawed and well drained, low when poorly drained. Slopes may stand at 1:1 to 2/3:1 except in unfrozen sand
Q_{cs}	Elongate, sinuous, flat-floored, meander and slough scars and wide shallow basinlike areas. Some intermittent streams present	Impermeable substratum of permafrost and organic silt in broad basinlike depressions creates poor drainage; marshy and undrained in summer. Drainage slightly better in linear scars. Drainage in both types improves slightly to moderately with land clearing and lowering of permafrost table. Subject to flooding	Depth to permafrost 1½–4 ft. Active layer 1½–4 ft. Permafrost 5–30 ft thick, continuous in broad basins, discontinuous in meander scars, generally absent in young sloughs. May be in contact with underlying perma*frost of river sand and gravel*. Moderate to high ice content as thin seams and lenses. Water table 10–15 ft where permafrost absent or deep	High	High bearing strength when frozen, very low when thawed. Slopes subject to sloughing and sliding upon thawing until well or moderately well drained

Table A2. USCS for coarse-grained sediments. (From Mathewson 1981.)

Unified Soil Classification System					
				Typical Names	Identification
Coarse-grained Soils More than half of material is larger than No 200 sieve size The no 200 sieve size is about the smallest particle visible to the naked eye	Gravels More than half of the coarse fraction is larger than no 4 sieve size (For visual classification, the ¼ in size may be used as equivalent to the no 4 sieve size)	Clean gravels (little or no fines)	GW	Well graded gravels, gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes
			GP	Poorly graded gravels or gravel sand mixtures, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing.
		Gravels with fines (appreciable amount of fines)	GM	Silty gravels, gravel sand silt mixtures	Nonplastic fines or fines with low plasticity
			GC	Clayey gravels, gravel sand-clay mixtures	Plastic fines
	Sands More than half of the coarse fraction is smaller than no 4 sieve size	Clean sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes
			SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing
		Sands with fines (appreciable amount of fines)	SM	Silty sands, silt-sand mixtures	Nonplastic fines or fines with low plasticity
			SC	Clayey sands, sand clay mixtures	Plastic fines.

APPENDIX A.

Table A1. Unified Soil Classification System (USCS) for fine-grained sediments. (From Mathewson 1981.)

				Identification Procedures on fraction smaller than no. 40 sieve size		
				Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (molding test)
Fine-grained Soils More than half of material is smaller than no. 200 sieve size The no. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to medium	None
		CL	Inorganic clays of low to medium plasticity, gravelly clays, silty clays, sandy clays, lean clays	Medium to high	None to very slow	Medium
		OL	Organic silts, and organic silty clays of low plasticity	Slight to medium	Slow	Slight, feels weak and spongy
	Silts and Clays Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to medium	Slight to medium
		CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High
		OH	Organic clays of medium to high plasticity, organic silt	Medium to high	None to very slow	Slight to med. spongy
Highly Organic Soils		Pt	Peat and other highly organic soils	Readily identified by color, odor, spongy feel, & frequently by fibrous texture		

Péwé, T.L. and J.W. Bell (1976c) Map showing groundwater conditions in the Fairbanks D-2SW quadrangle, Alaska. USGS Miscellaneous Investigations Series, Map I-829-C.

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Péwé, T.L. and J.W. Bell (1974) Map showing distribution of permafrost in the Fairbanks D-2SW quadrangle, Alaska. USGS Miscellaneous Investigation Series, Map I-829-B.

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Péwé, T.L. and J.W. Bell (1976b) Map showing foundation conditions in Fairbanks D-2SW quadrangle, Alaska. USGS Miscellaneous Investigations Series, Map I-829-E.

The USCS sediment classes, as generally defined, are not sufficiently dissimilar and do not give enough detailed sediment information to allow evaluation of differences in the sediment that may influence bank erodibility. Permafrost occurrences are about equal in eroded and uneroded sites, although it appears that recession can be higher where permafrost is common than where it is absent.

Because most of the results from the comparative analysis were inconclusive and because the surface sediments are so similar and the soils and vegetation root zones occur in only the upper few feet of the banks, the hydraulic forces of the river water (i.e. the distribution of currents, current velocities and meandering patterns), are almost certainly the predominant erosion factors. For most of the year, the river erodes a bank zone well below the upper few feet of the bank, and the similar sediments, soils and vegetation do not act as significant controlling factors of bank erosion.

I conclude that available data cannot be used to anticipate where future erosion may occur. A systematic field study of bank characteristics and erosion processes would be required to evaluate possible relationships among vegetation, bank sediment, permafrost, and erosion.

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reach 1 at a steeper angle from 1948 to 1980 than it did along reach 2, and therefore the erosive forces of the flow would be much higher. This is especially true along reach 1 from 1970 to 1980.

The sediment data for the two reaches are similar. The lack of any consistent relationships between sediments and recession suggests that the sediments do not influence bank erodibility enough to be detectable with the available data.

SUMMARY AND CONCLUSIONS

Available data on vegetation, soils, sediments and permafrost were compared to the locations and amounts of historical bank recession southeast of the Fairbanks International Airport. I found only inconclusive relationships between these data and the recession.

The differences in the vegetation units do not appear to be great, since each tree species of a given unit occurs in two other units found along the reaches. No vegetation unit occurred consistently in eroded areas. Cumulative recession data suggest that unit 2 vegetation is found where most recession occurs and unit 9 where it least occurs. However, recession measured during historical intervals does not relate in any consistent way to available vegetation units.

The Bradway soils that were eroded along reach 1 were absent in the eroded zone along reach 2. The Salchaket soils, eroded least along reach 1, were eroded most along reach 2. Along both reaches, Tanana soil was generally eroded the least. But any relationship between soils and bank recession is questionable. The soil only covers the upper 2 to 4 ft of the bank and the river erodes down to 32 ft along reach 1 and 18 ft along reach 2.

I suspect that apparent relationships between high recession and Bradway soil along reach 1 and Salchaket soil along reach 2 result from the fact that these two soils dominate along the respective reaches and are simply eroded more frequently than the others.

Along the two reaches, the sediments are similar in the eroded and uneroded wells and along transects with high and low recession. Sediments in the groups of eroded and uneroded wells are similar within and between the groups. As with the soils data, many of the apparent relationships were probably a result of one sediment type being dominant along the reaches and not due to real differences in bank erodibility.

were nearer the surface in well 124 (Fig. 14) than in the uneroded well 39 (which was drilled in the river channel). Nothing conclusive can be said based on data from one eroded well, but I do not think that a bank with gravel near the surface will necessarily be more erodible than a bank with gravel below the surface.

I made the following observations based on recession measurements and the well sediment data. Cumulative recession both greater and less than 400 ft occurred most frequently where ML predominated along the transect (Table 11). ML also was most common along the transects within the group where most recession occurred and along the highest recession transect during the four intervals. However, ML predominated where the lowest recession occurred. The dominant sediment was ML along the transects where recession was measured in each interval. There is very little difference between the sediment in the wells having the highest and lowest recession.

These results are inconclusive. It may be that ML is simply the most common sediment along the reach, and since the sediments are not different enough to affect bank erodibility, ML occurs where recession is highest and lowest. As along reach 1, the sediments along reach 2 are also similar and do not show sufficient differences to be useful in trying to explain if a particular bank location is more or less erodible than another.

Permafrost: Permafrost was not encountered in any of the wells along reach 2. Comparisons between sites with and without permafrost could not be made.

Discussion. Comparisons of the apparent erodibility of Q_c and Q_{cs} sediments and of bank sites with or without permafrost between reaches 1 and 2 could not be made because Q_{cs} sediment and permafrost did not occur along reach 2. The well data (Figs. 12 and 14) for the two reaches suggest that the sediments along reach 1 are more variable than those along reach 2. Also the sediments along reach 1 are generally coarser, although this may simply reflect the fact that the reach 2 wells were shallower and did not get into the coarser sediment as frequently. Visually comparing the logs in the upper 15 ft substantiates this.

Based on the available cross sections, the river eroded about 18 ft of the north bank along reach 2 and 32 ft along reach 1. Since more sands and gravels were eroded along reach 1, this may help explain the higher average recessions along reach 1 (Tables 4 and 5). This may also be explained by the river's angle of attack along the two reaches. The river hit the bank at

clusive can be said about the erodibility of sediments in well 124 compared to those in the adjacent uneroded wells.

Sediments - Site-Specific: Thirteen well logs (Fig. 14) along reach 2 were analyzed. I used three October 1979 cross sections (Fig. 8) to determine the depth of the north bank that could be eroded by the river. Earlier cross sections were not available. This depth varies from west to east: 13 ft (417 to 430 ft msl) along 7A, 15 ft (418 to 433 ft msl) along 8A, and 12 ft (421 to 433 ft msl) along X9. The sediment sizes increase with depth in the zone from 417 to 435 ft msl (Table A8).

Generally the upper 10 ft of the bank are peat (PT) and inorganic silts (ML), while the lower part is silty to gravelly sands (SM to SP) and sandy to clean gravels (GP-GW) (Table A8). The silts have low permeability and shear strength and high compressibility (Table A3). The sands have low to high permeability, medium to high shear strength and medium to low compressibility. The gravels are highly permeable, have high shear strength and low compressibility.

The most common sediment class in the one eroded well was GW, while ML and PT were secondary (Table 11). ML dominated in 10 of the 12 uneroded well sites, suggesting that the larger sediments along reach 2 may be more erodible.

The sediment in the eroded well (Table A9; Fig. 15) had a higher percentage of gravels than that in the uneroded wells (Table A10). These gravels

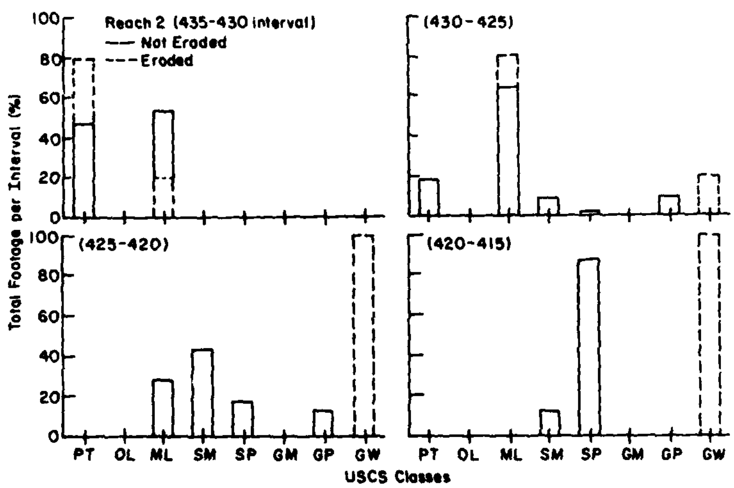

Figure 15. Sediments in eroded and uneroded wells, reach 2.

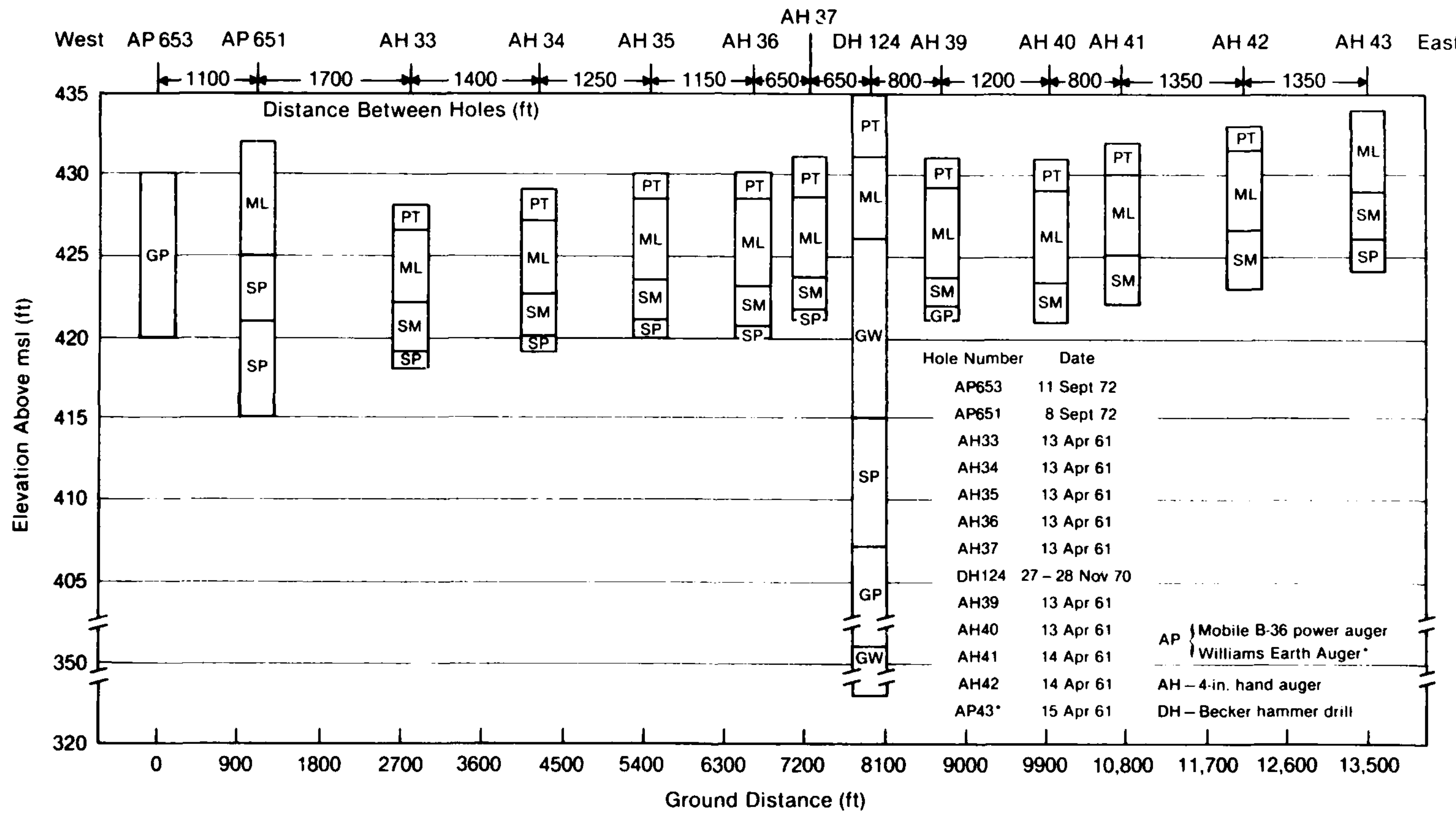

Figure 14. Well logs, reach 2.

above 422 ft msl, which is above the portion of the bank affected by the river for most of the year.

A comparison of eroded and uneroded wells in regard to permafrost occurrence gives the following observations. In the eight eroded wells (Tables 2 and 11), five (2165, 2169, 2170, 2164 and 2228) had only seasonal frost to a depth of 2.5 ft and three wells (2229, 2171, and 2101) had permafrost up to a depth of 0-28 ft. In the 10 uneroded wells, five (2172, 2168, 2293, 2102 and 2104) had permafrost that was up to 50 ft deep. Most of the permafrost in uneroded well 2168 was below the 32-ft erosion zone (Fig. 12). Five uneroded wells and three eroded wells had permafrost within the erosion zone. This suggests that the presence of permafrost cannot be used to predict where bank erosion may occur.

Permafrost occurred along 5 of 13 (38%) transects where cumulative recession was greater than 600 ft (Table 11). Two of five (40%) transects in that part of the reach where recession was less than 600 ft had permafrost. The similarity of these percentages also suggests that permafrost may not affect bank erosion. This is speculative, however, considering the previously mentioned shortcomings of the available data.

Permafrost predominated along transects where the most recession occurred during two intervals, yet from 1961 to 1970 none of the transects in the high-recession group had permafrost (Table 11). Along the transects where recession was highest or lowest during an interval, permafrost was present about as frequently as it was absent (Table 11).

Permafrost was absent more often than it was present along transects where recession occurred during each interval except during the 1970-1975 interval. Recession during this interval was 250 ft, the highest of the four intervals (Table 4). This suggests that more recession may occur where permafrost is common along a bank.

Reach 2. Sediments - General: The Q_{cs} sediments do not occur along reach 2 within the area of the bank eroded from 1966 to 1980. So it is impossible to speculate about the comparative erodibility of these units along reach 2.

Only well 124 was eroded from 1970 to 1980 (Table 5) and its measured recession was variable. From 1970 to 1975 the bank near well 124 receded 260 ft but it did not recede at all from 1975 to 1980 (Table 6). While the banks adjacent to uneroded wells 651 and 33 receded in both intervals, nothing con-

sediments at the same levels in the uneroded wells, which seems contrary to what would be expected.

Clean to sandy gravels (GP) are the predominant sediments in four of eight eroded wells and one of 10 uneroded wells (Table 2). Silty to gravelly sands (SM-SP) predominate in three of the eroded and six of the uneroded wells. Inorganic silts (ML) are dominant in one of the eroded and three of the uneroded wells. This suggests that wells with finer-grained sediments in the column are more stable than those with coarser sediments.

The highest cumulative recession (>600 ft) occurred along 13 transects through wells 2170 to 662 (Table 2). Silty to gravelly sands (SM-SP) dominated along seven clean to sandy gravels (GP) along three, and inorganic silts (ML) along three. Cumulative recession less than 600 ft occurred along five transects. The dominant sediment was SM-SP along two, GP along two and ML along one. The lowest and highest cumulative recession occurred in wells with very similar sediments (Table 2).

The analysis of the interval recession produced the following results. The transects with most recession had predominantly SM and SP or GP sediments (Table 2). Each sediment class was dominant during two intervals. The intervals with the highest and lowest average recession (Table 3) had similar sediments along the group of transects where the most recession occurred.

The sediment along the transect with the highest recession during two intervals was GP, while it was ML and SM during one (Table 11). The same classes were also dominant along transects with the lowest recession during various intervals. The dominant sediments in every interval were SP and SM, and in decreasing order, GP and ML (Table 11). Even though the average recession varied per interval (Table 4) no obvious major difference was discernible from the available sediment data. This suggests that either these data cannot be used for defining bank sediment differences sufficiently to evaluate their erodibility or that the sediments are similar enough that they do not influence erosion preferentially in any way.

Permafrost: The distribution of frozen ground detected in the wells does not show any relationship to the location of the eroding bank. The deepest frozen ground is at well 2168 (Fig. 12). Most of the frozen ground deep enough to be eroded by the river was located in wells 2104, 2102, 2101, 2293, 2172, 2171, and 2229. The zone of most recession (wells 2169 to 2101) has frozen ground that is variable; for example, 2171 was frozen to about 28 ft and 2173 was unfrozen. At most of the other wells, frozen ground is found

produced inconclusive results and the comparisons using the site-specific well log data were equally inconclusive.

Sediments - Site-Specific: Sediment data (Table A5) obtained from 18 well logs (Fig. 12) show the following. Generally along reach 1, the upper 15 ft of the bank (410 to 425 msl) is predominantly composed of silts and fine sands (ML, Table A1) near the surface (Table A5) with silty sands (SM) and gravelly sands (SP) at depth. The silts and fine sands have low permeability and shear strength and high compressibility (Table A3). The silty sands have low to medium permeability and medium shear strength and compressibility. Gravelly sands are highly permeable, having high shear strength and low compressibility. Below 410 msl (Table A5), most of the bank sediment is poorly graded sand or gravelly sands (SP) and clean gravels (GP). The GP gravel has very high permeability, high shear strength and low compressibility.

The sediments in the group of eight eroded wells (Table A6) and in the group of 10 uneroded wells (Table A7) are similar to those along the reach as a whole (Table A5) and are similar to each other (Fig. 13). In most of the classes within the seven depth intervals (Fig. 13), the difference between the groups of eroded and uneroded wells was in the percentage of a particular class, and the dominant sediment class in the eroded and uneroded wells was the same at four of the seven levels. In the 430- to 425-ft interval there was only one well (Fig. 13). The dominant sediment, SM and GP, at two of the three remaining levels in the eroded wells had higher shear strength than the

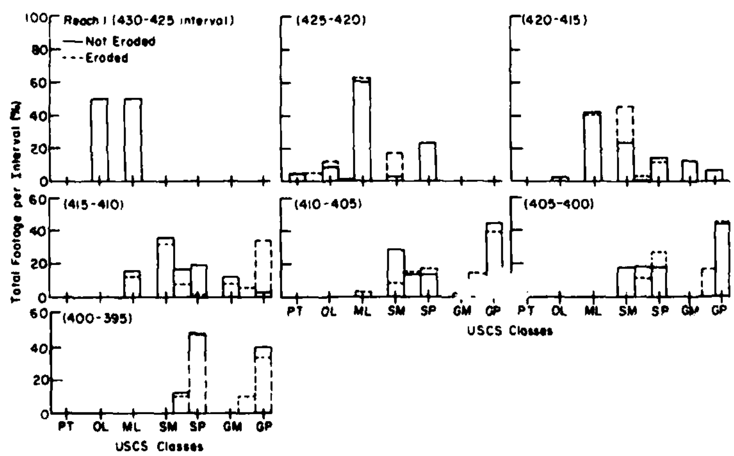

Figure 13. Sediments in eroded and uneroded wells, reach 1.

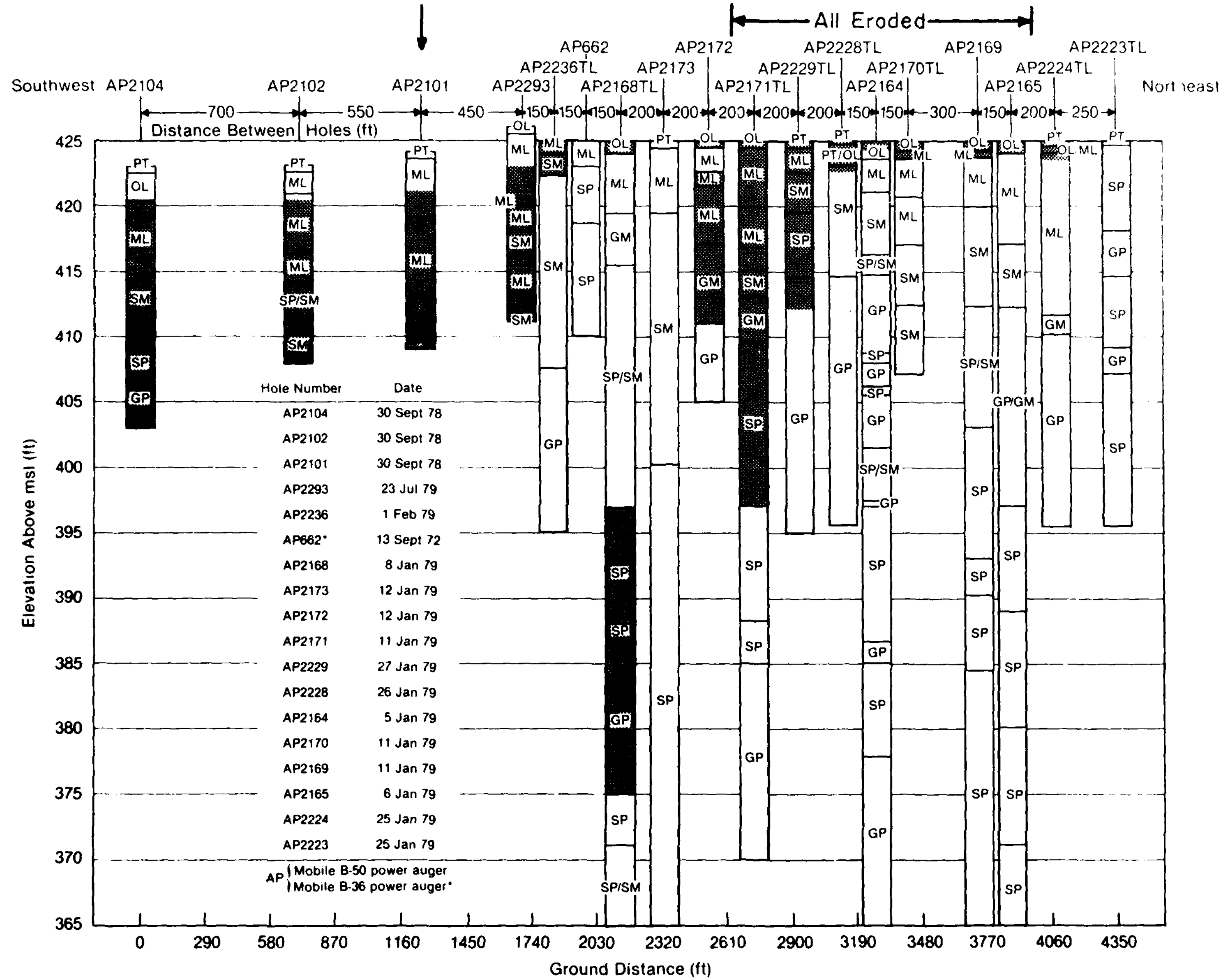

Figure 12. Well logs, reach 1; stipled areas were frozen when drilled.

Table 11. Summarized results of the sediments and permafrost analysis.

Analytical Method	Reach 1			Reach 2††
	Q_c vs Q_{cs}	Well Log Data**	Permafrost	Well Log Data**
Method 1				
Eroded wells	6 of 8 (75%)-Q_c 2 of 8 (25%)-Q_{cs}	4 of 8 (50%)-GP 3 of 8 (38%)-SM,SP 1 of 8 (12%)-ML	5 of 8 (62%)-No 3 of 3 (38%)-Yes 3 of 8 (38%)-Yes	1 of 1 (50%)-GW
Uneroded wells	7 of 10 (70%)-Q_c 3 of 10 (30%)-Q_{cs}	6 of 10 (60%)-SM,SP 3 of 10 (30%)-ML 1 of 10 (10%)-GP	5 of 10 (50%)-No 5 of 10 (50%)-Yes	10 of 12 (84%)-ML 1 of 12 (8%)-GP 1 of 12 (8%)-SP
Method 2				
Cumulative recession*	13 of 13 (100%)-Q_c	7 of 13 (54%)-SM,SP 3 of 13 (23%)-GP 3 of 13 (23%)-ML	8 of 13 (62%)-No 5 of 13 (38%)-Yes	3 of 4 (75%)-ML 1 of 4 (25%)-SP
Cumulative recession†	5 of 5 (100%)-Q_c	2 of 5 (40%)-SM,SP 2 of 5 (40)-GP 1 of 5 (20%)- L	3 of 5 (60%)-No 3 of 5 (40%)-Yes	7 of 9 (78%)-ML 2 of 9 (22%)-GP,GW
Transects with Most Recession				
1948-1961	No data	3 of 6 (50%)-SM,SP 3 of 6 (50%)-ML	4 of 6 (66%)-Yes	2 of 2 (100%)-ML
1961-1966(1970)	No data	4 of 7 (57%)-GP 3 of 7 (43%)-SP,SM	7 of 7 (100%)-No	1 of 2 (50%)-SP 1 of 2 (50%)-ML
1966(1970)-1975	7 of 8 (88%)-Q_c	5 of 9 (56%)-SP,SM 2 of 9 (22%)-GP 2 of 9 (22%)-ML	5 of 9 (56%)-Yes	3 of 4 (75%)-ML 1 of 4 (25%)-GW
1975-1980	5 of 7 (71%)-Q_c	3 of 7 (43%)-GP 3 of 7 (43%)-SP,SM 1 of 7 (14%)-ML	4 of 7 (57%)-No	2 of 3 (66%)-ML 1 or 3 (34%)-SP
Transect With Highest Recession				
1948-1961	No data	97%-ML	Yes	45%-ML
1961-1966(1970)	No data	50%-GP	No, 1 of 2 (50%)-Yes	56%-ML
1966(1970)-1975	Q_c	64%-SM		1 of 2 (50%)-GW 1 of 2 (50%)-ML
1975-1980	Q_c	41%-GP	No	59%-SP
Transects with Lowest Recession				
1948-1961	No data	66%-GP	Yes	6 of 8 (75%)-ML 1 of 8 (13%)-SP 1 of 8 (13%)-GP
1961-1966(1970)	No data	64%-SM 61%-SP/SM	1 of 2 (50%)-Yes	6 of 8 (75%)-ML 2 of 8 (25%)-GP,GW
1966(1970)-1975	6 of 7 (86%)-Q_c 1 of 7 (14%)-Q_{cs}	4 of 7 (57%)-SM,SP 2 of 7 (29%)-GP 1 of 7 (14%)-ML	5 of 7 (71%)-No	3 of 4 (75%)-ML 1 of 4 (25%)-GP
1975-1980	3 of 3 (100%)-Q_c	2 of 3 (66%)-SM,SP 1 of 3 (34%)-GP	2 of 3 (66%)-No	8 of 10 (80%)-ML 2 of 10 (20%)-GW,GP
Dominant Sediment Per Interval				
1948-1961	No data	9 of 17 (53%)-SP,SM 4 of 17 (24%)-GP 4 of 17 (24%)-ML	10 of 17 (59%)-No	4 of 5 (80%)-ML 1 o 5 (20%)-GW
1961-1966(1970)	No data	7 of 16 (44%)-SP,SM 5 of 16 (31%)-GP 4 of 16 (25%)-ML	9 of 16 (56%)-No	4 of 5 (80%)-ML 1 of 5 (20%)-SP
1966(1970)-1975	10 of 11 (91%)-Q_c 1 of 11 (9%)-Q_{cs}	5 of 11 (46%)-SP,SM 3 of 11 (27%)-GP 3 of 11 (27%)-ML	6 of 11 (55%)-Yes	7 of 9 (78%)-ML 1 of 9 (11%)-GW 1 of 9 (11%)-SP
1975-1980	11 of 15 (73%)-Q_c 4 of 15 (27%)-Q_{cs}	7 of 15 (46%)-SP,SM 4 of 15 (27%)-GP 4 of 15 (27%)-ML	6 of 15 (53%)-No	2 of 3 (66%)-ML 1 of 3 (34%)-SP

* >600 ft, Reach 1; >400 ft, Reach 2
† <600 ft, Reach 1; <400 ft, Reach 2
** Dominant sediment class
†† Reach 2 had only Q_c and no permafrost reported in the well logs, so no comparisons could be made

Table A3. Sediment properties based on the USCS. (From Mathewson 1981.)

Unified Soil Classification	Permeability*	Shear Strength*	Compressibility*
GW	High	Very high	Very low
GP	Very high	High	Low
GM	Low to medium	High	Low
GC	Very low to medium	Medium	Medium
SW	High	Very high	Very low
SP	High	High	Low
SM	Low to medium	Medium	Medium
SC	Very low to low	Low	High
ML	Low	Low	High
MH	Very low to low	Very low	Very high
CL	Low	Very low	Very high
CH	Very low	Very low	Very high

*Determined on compacted, saturated samples.

Table A4. Grain size scales for sediments. (From Folk 1968.)

U.S. Standard Sieve Mesh #		Millimeters	Microns	Phi (ø)	Wentworth Size Class	
		4096		-12		
		1024		-10	Boulder (-8 to -12ø)	
Use		256		- 8	Cobble (-6 to -8ø)	
wire		64		-6		
squares		16		-4	Pebble (-2 to -6ø)	GRAVEL
5		4		-2		
6		3.36		-1.75		
7		2.83		-1.5	Granule	
8		2.38		-1.25		
10		2.00		-1.0		
12		1.68		-0.75		
14		1.41		-0.5	Very coarse sand	
16		1.19		-0.25		
18		1.00		0.0		
20		0.84		0.25		
25		0.71		0.5	Coarse sand	
30		0.59		0.75		
35	1/2	0.50	500	1.0		
40		0.42	420	1.25		
45		0.35	350	1.5	Medium sand	
50		0.30	300	1.75		
60	1/4	0.25	250	2.0		SAND
70		0.210	210	2.25		
80		0.177	177	2.5	Fine sand	
100		0.149	149	2.75		
120	1/8	0.125	125	3.0		
140		0.105	105	3.25		
170		0.088	88	3.5	Very fine sand	
200		0.074	74	3.75		
230	1/16	0.0625	62.5	4.0		
270		0.053	53	4.25		
325		0.044	44	4.5	Coarse silt	
		0.037	37	4.75		
	1/32	0.031	31	5.0		
	1/64	0.0156	15.6	6.0	Medium silt	
Analyzed	1/128	0.0078	7.8	7.0	Fine silt	MUD
by	1/256	0.0039	3.9	8.0	Very fine silt	
		0.0020	2.0	9.0		
Pipette		0.00098	0.98	10.0	Clay	
		0.00049	0.49	11.0		
or		0.00024	0.24	12.0		
		0.00012	0.12	13.0		
Hydrometer		0.00006	0.06	14.0		

Table A5. General sediment distribution, within the 32-ft deep erosion zone, reach 1 (data from Figure 12).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)
430-425	1	1		.5 (50)	.5 (50)				
			-----1.7 (2)------	.5 (1)------					
425-420	85	18	3.5 (4)	8.4 (10)	52.5 (62)	7.9 (9)	10.5 (12)		
420-415	90	18		1.2 (1)	36.8 (41)	29.7 (33)	11.6 (13)	6.1 (7)	3.1 (3)
						--------1.6 (2)--------			
415-410	89	17			12.5 (14)	29.9 (33)	10 (11)	8.5 (10)	15.3 (17)
						-------10.6 (12)--------		-------2.2 (3)-------	
410-405	71	16			1 (1)	13.5 (19)	10.8 (15)	.6 (1)	30.1 (42)
						--------10 (14)---------		--------5 (7)--------	
405-400	57	12				4.8 (8)	13.2 (23)		25.6 (45)
						-------8.9 (15)---------		--------5 (9)--------	
400-395	54	11					25.4 (47)		19.5 (36)
						-------5.6 (11)---------		-------3 (6)---------	
395-390	30	6					30 (100)		

Table A6. Sediments in the group of eight eroded wells, reach 1 (data from Figure 12).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)
430-425	0	0							
425-420	39	8	1.4 (4)	4.5 (11)	24.7 (63)	6.5 (17)			
			------1.7 (5)-----						
420-415	40	8			16.2 (40)	18 (45)	4.5 (11)		
						-------1.3 (3)-------			
415-410	40	7			5 (13)	12.8 (32)	5 (1)	3 (7)	13.7 (34)
						-------2.7 (7)-------		------2.3 (6)-----	
410-405	34	8			1 (3)	3 (9)	5.8 (17)	.6 (2)	13.6 (40)
						--------5 (15)-------		------5 (15)------	
405-400	30	6					8 (28)		13.6 (45)
						------3.4 (11)-------		------5 (17)------	
400-395	29.5	6					14 (47)		9.9 (34)
						------2.6 (9)--------		------3 (10)------	
395-390	20	4					20 (100)		

Table A7. Sediments in the group of 10 uneroded wells, reach 1 (data from Figure 12).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)
430-425	1	1		.5 (50)	.5 (50)				
425-420	46	10	2 (4)	3.8 (8)	27.8 (60)	1.4 (3)	10.5 (23)		
				------.5 (1) ------					
420-415	50	10		1.1 (2)	20.5 (41)	11.7 (23)	7.1 (14)	6.1 (12)	3.1 (6)
						--------.3 (1) --------			
415-410	49	10			7.5 (15)	17.1 (35)	9.5 (19)	5.5 (11)	1.6 (3)
						------7.9 (16) --------			
410-405	37	8				10.5 (28)	5 (14)		16.5 (44)
						------5 (14) ----------			
405-400	27	6				4.8 (18)	5.2 (19)		12 (44)
						------5 (19) ----------			
400-395	24	5					11.4 (47)		9.6 (40)
						------3 (13) ----------			
395-390	10	2					10 (100)		

Table A8. General sediment distribution within the 18-ft deep erosion zone, reach 2 (data from Figure 14).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)	GW Tot. ft. (%)
435-430	19	8	10.6 (56)		8.4 (44)					
430-425	62	13	10 (16)		40.4 (65)	4.6 (7)	1 (2)		5 (8)	1 (2)
425-420	53	13			13.5 (20)	20.5 (39)	8.2 (15)		5.8 (11)	5 (9)
420-415	13	4				1 (8)	7 (54)			5 (38)

Table A9. Sediments in the one eroded well, reach 2 (data from Figure 14).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)	GW Tot. ft. (%)
435-430	5	1	4 (80)		1 (20					
430-425	5	1			4 (80)					1 (20)
425-420	5	1								5 (100)
420-415	5	1								5 (100)

Table A10. Sediments in the group of 12 uneroded wells, reach 2 (data from Figure 14).

Elevation Intervals (ft)	Total Footage	Number of Wells	PT Tot. ft. (%)	OL Tot. ft. (%)	ML Tot. ft. (%)	SM Tot. ft. (%)	SP Tot. ft. (%)	GM Tot. ft. (%)	GP Tot. ft. (%)	GW Tot. ft. (%)
435–430	14	7	6.6 (47)		7.4 (53)					
430–425	57	12	10 (17)		36.4 (64)	4.6 (8)	1 (2)		5 (9)	
425–420	48	12			13.5 (28)	20.5 (43)	8.2 (17))		5.8 (12)	
420–415	8	3				1 (12)	7 (88)			

DAT

FILM